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ABSTRACT

The role lectures play in problem-based learning was studied. The hypothesis was that lecture quality would have a positive influence on the time students would spend in study, that it would increase intrinsic interest in subject matter and would have a positive influence on achievement. Lecture quality would add to the other factors that play a role in problem-based learning, such as prior knowledge, the quality of the problems, the functioning of the tutor, and small-group collaboration. To test these hypotheses, data from 1,500 undergraduate students were analyzed. It was concluded that lecture quality did not affect the time spent in study, does not add to achievement, and does not influence intrinsic interest in the subject mater. Post-hoc analyses, however, demonstrated the quality of lectures to be related to other components of problem-based learning, which were not part of the presented model, such as students' perceptions of lectures as organizers of study efforts, or lectures as a means of putting the problem into a broader perspective. (Contains 4 tables, 3 figures, and 42 references.) (Author/SLD)

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THE ROLE OF LECTURES IN PROBLEM-BASED LEARNING

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ABSTRACT

The purpose of this article is to report on a study conducted to investigate the role lectures play in problem-based learning. We hypothesized that lecture quality would have a positive influence on time students would spend on self-study, that they would increase intrinsic interest in subject matter, and would have a positive influence on achievement. Lecture quality would, in this view, add to other factors that play a role in problem-based learning, such as prior knowledge of students, the quality of problems presented, the functioning of the tutor, and small-group collaboration. To test the hypothesis on the influence of lecture quality on learning, data from 1500 students were analyzed. We concluded that lecture quality does not affect time spent on study, does not add to achievement and does not influence intrinsic interest in subject matter. Post-hoc analysis, however, demonstrated the quality of lectures to be related to other components of problem-based learning, not part of the presented model, such as students' perceptions of lectures as organizer of their study efforts, or lectures as a means of putting the problems into a broader perspective.

INTRODUCTION

The purpose of this article is to report on a study designed to investigate the role that lectures play in problem-based curricula. Problem-based learning (PBL) is a by now well-established method of learning and instruction (Kaufman and Mann, in press). Although originally developed in the context of medical education, the method has been implemented in other domains as well (Gijselaers, Tempelaar, Keizer, Blommaert, Bernard and Kasper, 1995). PBL emphasizes small-group work on problems and self-directed learning and de-emphasizes teacher-controlled activity such as lectures. This is so because lecturing has repeatedly been shown to be quite ineffective as a means of improving learning and

achievement (Bligh, 1998). Lecturing does not particularly advance problem-solving skills, nor does it require creative or critical thinking, or prepare students for the types of problems they will face as professionals (Johnson, 1999). These are just the characteristics that PBL claims to impart on students. Before turning to the issue of lectures and PBL, we will briefly review recent studies comparing effects of lecture-based learning (LBL) programs with those of PBL on student learning. For reviews of the somewhat older literature, the reader is referred to Albanese and Mitchell (1993), Vernon and Blake (1993), or Schmidt, Dauphinee, and Patel (1987).

Review of studies comparing PBL with LBL

In England, the General Medical Council recommended, in 1993, major changes in the medical undergraduate course, e.g. reducing the duration of the curriculum. In response, the Nottingham school of medical education shortened the curriculum and replaced the lectures by problem-oriented small workshops. After this curriculum innovation, Singh, Baxter, Standen and Duggan (1998) compared the attitudes of students towards psychiatry and mental illness. They concluded that, notwithstanding the substantial reduction, the new curriculum appeared to be as effective as a longer curriculum. Lancaster, Bradley, Smith, Chessman, Stroup-Benham and Camp (1997) and Kaufman and Mann (1997) also reported that the attitudes of PBL students were significantly more positive than those of LBL students.

The Medical Faculty of the University of Cologne in Germany also attempted to replace lectures by PBL. In their evaluation of this curriculum change, Antepohl and Herzig (1999) in particular investigated the changes in factual knowledge of the students. It seemed that PBL did not imply a disadvantage in terms of factual knowledge. Moreover, students considered PBL to be an effective learning method and favored it over the lecture format. Furthermore, students reported positive effects of PBL in terms of use of additional learning resources, interdisciplinarity, teamwork, and learning fun. In general, results show a favorable impact of

PBL on perceptions of the academic environment (Lieberman, Stroup-Benham, Peel and Camp, 1997; Lancaster et al., 1997).

A study by Login, Ransil, Meyer, Truong, Donoff and McArdle (1997) reported better results on medical knowledge tests of PBL students comparing to LBL students. There is also evidence (Cariaga-Lo and Richards, 1996) that students entering a PBL curriculum score higher on the Medical College Admission Test in the United States and have a higher undergraduate grade point average than students who entered the LBL curriculum. This suggests that sometimes the prior knowledge or even the learning skills of medical students who are given the choice between a PBL and a LBL curriculum may be different. On the other hand, Aaron, Crocket, Morrisk, Basulado, Kovihavongs, Mileke and Cook (1998) reported a controlled study which indicates that PBL students acquire better learning styles leading to higher scores on exam questions which examine elaborated knowledge contrary to dispersed knowledge. To what extent this result can indeed be attributed to their learning styles is unclear. Menec, Perry and Struthers (1995) showed that although PBL scored higher achievement tests, the results are to a large degree explained by students' personal characteristics. Camp, Hollingsworth, Zaccaro, Cariaga-Lo et al. (1994) also demonstrated that students' characteristics could cause the differences between the achievements scores.

Within the context of continuing medical education, Doucet, Prudy, Kaufman and Langille (1998) conducted a study in which they compared PBL and LBL students in terms of knowledge and clinical reasoning with respect to the diagnosis of headache. The PBL group scored significantly higher on both dimensions. In addition, the satisfaction of PBL students with several program aspects was significantly higher that that of the lecture group. Schreiber (1997) and Richards, Ober, Cariaga-Lo, Camp, Philp, McFarlane, Rupp and Zaccaro (1996) conducted a similar study in the domain of internal medicine. The results also favored PBL.

There is also evidence that PBL students spent more time preparing the Medical Licensing Examination (Richards and Cariaga-Lo, 1994). This result was seen as a positive effect of the PBL curriculum. In another study, however, the increase in study time was seen as a disadvantage (Rand and Bagliono, 1997). As will be discussed further on, time spent on

individual study is a variable in educational research that is difficult to explain by elements of the learning situation, be it small-group learning or lecture-based learning. Van Berkel and Schmidt (accepted), for instance, examined a path-analytic PBL model in which several elements of PBL were investigated, including self-study time. A multiple R-coefficient, indicating the extent to which self-study time was explained by other variables, only reached a value of .20.

Thus, although some studies have revealed inconsistencies, the overall results indicate relatively strong evidence in favor of PBL compared to LBL on some important learning outcomes. However, do these results imply that lectures could be discarded from problem-based curricula? It is generally believed that lectures have some positive role to play in a PBL curriculum too. A lecture as a means of transmitting knowledge to students may be ineffective. However, lectures can clarify for students the underlying structure of the curriculum, they can guide students to undertake learning activities in a desirable direction, and they can arouse interest in the subject matter (Bligh, 1998). The question arises if it is possible to design a curriculum in which lectures are an integral part of the learning process, not disrupting but reinforcing it? Would these lectures, under these conditions, contribute to the learning outcomes?

Integrating lectures into a model of problem-based learning

The studies reviewed thus far concentrate on comparisons of outcomes of different types of curricula. These studies largely ignore those elements in the curricula that are responsible for the different outcomes. In particular, if one is interested in the relative contributions of the quality of lectures to students' learning processes, one needs a different approach, an approach more geared toward the processes of learning and instruction that lead to the various outcomes. Such an approach is the models-of-school-learning approach advocated by Carroll (1963) and Bloom (1976). In their view, learning within the context of a

school can be described by three categories of variables. The first category contains input variables such as the characteristics of students, the behavior of teachers and the learning materials. The second category comprises the intervening process variables: Learning activities carried out by students, time spent on study and features of the instructional process. The third category consists of cognitive output variables, e.g. achievement, and affective outcomes like interest in subject matter studied. Relationships between these variables should in the view of the models-of-school-learning approach, be the focus of educational research. Gijselaers and Schmidt (1989) have proposed a theoretical model of problem-based learning that is based on this approach to learning and instruction (see Figure 1).

(Here Figure 1)

The input variables are the student's prior knowledge, the quality of the problems, and the effectiveness of the tutor. The intervening process variables are the extent to which the tutorial group functions effectively and the amount of time students spend on self-directed activities. The output variables are identified as the score on the achievement test and the increased interest in the topic studied. The arrows in Figure 1 indicate the directions of the influences from one variable to another. According to the model, an increase in the magnitude of one of the variables causes an increase of the magnitudes of other variables.

In a series of studies, applying structural equations modeling techniques (Bentler, 1989), Gijselaers and Schmidt (1989), Schmidt and Gijselaers (1990), and Schmidt (1999) found empirical support for this model. More recently, Van Berkel and Schmidt (submitted) added another intervening variable to the model, namely the willingness, or commitment, of students to actually engage in the problem-based learning process, operationalized in terms of attendance of tutorial group meeting. This extension improved the model slightly, but significantly.

The present study extends this work. It directs attention to the influence of lecture quality on the proposed problem-based learning model as represented in Figure 1. Lectures can be seen as an independent source of information on what to study and how to study and, therefore, be considered as an input variable, in addition to prior knowledge, the quality of a problem and the effectiveness of the tutor.

The purpose of the present study was to investigate whether the quality of lectures contributes to improving the predictions of the PBL model as displayed in Figure 1; that is: To ascertain that lectures have a positive influence on learning in problem-based curricula. To that end, the variables of interest were measured in a population of health sciences students using questionnaires and achievement tests. The resulting data were analyzed using structural equations modeling.

METHOD

Subjects and procedure

Subjects were approximately 1500 undergraduates enrolled in a problem-based, four-year health sciences curriculum. Students worked in tutorial groups of ten students. A tutor guided each group. The curriculum of the first three years consisted of series of consecutive units, each of them lasting six weeks. In these six weeks, six to ten lectures were scheduled. At the end of every unit, students filled out a questionnaire detailing aspect of the learning experience in the particular unit. The response rate was about 80% for each unit. The 7000 questionnaires returned form the basis of the investigation. However, data were aggregated because some variables cannot be considered independent scores (Marsh, 1980). First, variables such as lecture quality and quality of problems are dependent on the specific unit of which they are part. Thus, scores on these variables were aggregated at the unit level. Next, all other variables were aggregated at the tutorial group level because achievement and

other variables are related to members of the same tutorial group and therefore cannot be considered independent scores. So finally, the level of analysis was the tutorial group. In total, 700 groups were involved in the study.

Instruments

As stated above, at the end of each unit students fill out a rating scale, consisting of 23 Likert-type items, covering the various dimensions of PBL as outlined in Figure 1. The Likert-type items could be answered on a 5-point scale, which varied from totally disagree to totally agree. In previous factor-analytic, reliability and validity studies, these dimensions have shown to have acceptable intraclass-coefficients as a measure of interrater agreement and construct validity (Schmidt, Dolmans, Gijselaers, and Des Marchais, 1995). The items given in Table 1 operationalized the variables in the model. In some cases, more than one item was related to a specific variable.

(Here Table 1)

In addition, an achievement test was administered to each student at the end of each unit. The raw scores were transformed to a 4-point scale (1 indicating insufficient; 2 doubtful; 3 sufficient; 4 good).

Statistical analysis

The goal of this investigation was to study the supplemental merit of lecture quality to the PBL model. The two models, one without the lecture quality, the general PBL model, and one with lecture quality as one of the components, were compared. In order to do so, a good starting point is to investigate the model fit of the general PBL model as proposed in Figure 1. Although the model has not been rejected in several studies (Schmidt and Gijselaers,

1989, Van Berkel and Schmidt, 1999), it is a well-known fact that the fitting of a model is to a certain degree dependent on sample used (Schmidt, 1999). Therefore, each investigation, which uses the general PBL model as a starting point, must also include a study to the model fit. The model fit procedure (Bollen, 1989) yields several statistics that allow the investigator to assess the extent to which the empirical data fit the theoretical proposed. Unfortunately, there is no single best statistic that gives insight into the fit of the model. In addition, there are no criteria to evaluate the statistic, e.g. by a test of significance (Arbuckle and Wothke, 1999), although some authors give rules of thumb. The best a researcher can do is computing several statistics, which reflect the fit of the model. The coherence of these measures indicates the model-fit. Browne and Mels (1992) recommend restricting the statistics to the following indices: CMIN, P, FMIN, F0, PCLOSE, and RMSEA. However, while following Browne and Mels (1992), we will add indices recommended by Marsh and Yeung (1998): TLI and CFI.

These indices can be characterized as follows. Indices such as CMIN, P, and FMIN reflect the discrepancy between the covariances in the sample and those in the population. They differ from each other in the way they handle the constraints. Arbuckle and Wothke (1999) argue that the CMIN is the best index of fit. This index is computed by dividing the minimum discrepancy C by its degrees of freedom. The ratio must be less than 5 and preferably less than 3 and close to 1 for correct models. FMIN is another index based on the discrepancy between the sample and the population. Values below 0.05 indicate good fit. Based on the well-known chi-square and the degrees of freedom, a level of significance (p) is computed. In order not to reject the model, it is preferred that the p-value is higher than .05. In investigations with a large sample (as is the case in this study), p is, however, not a proper index to reflect the fit of the model. This has to do with the fact that statistical hypothesis testing can be a poor tool for choosing a model (Jöreskog, 1967). Models are never perfectly correct and thus can always be rejected on statistical grounds. Large samples often lead to significant results and to rejecting the null hypothesis. In the case of model-fitting the null hypothesis is: The covariances in the sample are the same than in the population. The larger

the sample, the more likely the null-hypotheses is to be rejected (Arbuckle and Wothke, 1999; Mulaik, personal communication).

Steiger (1990) recommend the use of the discrepancy function (F0) obtained by fitting a model to the population moments rather than to the sample moments. From F0 there are other indices deduced depending on the estimation of F0 and related quantities. F0 incorporates no penalty for model complexity and will tend to favor models with many parameters. A general rule is: "The more parameters there are, the better the fit". Steiger (1990) suggests compensating for the effect of model complexity by dividing F0 by the number of degrees of freedom. Taking the square root of the resulting ratio gives the population root mean square error of approximation, called RMSEA (Browne and Cudeck, 1993). They also give a rule of thumb for the fit. A value of 0.05 or less would indicate a close fit of the model in relation to the degree of freedom. Of course, a value of zero indicates exact fit. PCLOSE is a "p-value" for testing the null hypothesis that the population RMSEA is no greater than 0.05. (By contrast, the 'p' mentioned above represents the p-value testing the hypothesis that the population RMSEA is zero.) Besides indices that compare the hypothesized model with the sample or population moments, there are other interesting indices, which compare the discrepancy of the model with the independence model. In an independence model, it is hypothesized that the observed variables are not correlated. The model therefore fits very badly. By comparing the observed fit with the *worst-case scenario*, the outcomes of the fit procedure obtain some perspective. Two of these indices are the Tucker-Lewis index, TLI (Bentler and Bonnett, 1980), and the comparative fit index, CFI (Bentler, 1990). They both yield values between zero and one (although theoretically TLI can be higher). Values close to one indicate a very good fit.

RESULTS

Table 2 shows the intercorrelations, means and standard deviations of the variables.

(Here Table 2)

The theoretical model displayed in Figure 1 was tested against these data. There were 700 groups involved in this study. This is a relatively large number, which implies that the fit indices commonly used such as the Chi square and P, are not applicable (Arbuckle and Wothke; 1999). The values of other indices are: CMIN: 27.32; FMIN: 0.48; FO: 0.46; PCLOSE: 0.00; RMSEA: 0.20; TLI: 0.38, and CFI: 0.64. These findings indicate that the theoretical model displayed in Figure 1, does not adequately describe the data. Other authors (Gijselaers and Schmidt, 1989; Schmidt, 1999; Van Berkel and Schmidt, submitted) found a similar model to be too restrictive as well. Therefore, we studied several feasible alternatives to the present model. The best of these is displayed in Figure 2.

(Here Figure 2)

Compared to the original model, two causal relationships were added: one between Amount of Prior Knowledge and Intrinsic Interest in Subject Matter, and one between Quality of the Problems and Intrinsic Interest in Subject Matter. These additions improved the description of the data substantially, as can be seen Tables 3 and 4. The purpose of our research was to investigate the supplemental merit of lecture quality to the PBL model. Therefore, in addition to the modified PBL-model (model A), as displayed in Figure 2, we added an alternative model (model B) which included the new variable 'Lecture quality' (see Figure 3). We assumed, based on the theoretical considerations mentioned in the introduction part of this paper, that lecture quality influences time spent on study, intrinsic interest in subject matter and achievement score.

(Here Figure 3)

Arrows in Figures 2 and 3 indicate the standardized output of the hypothesized causal influences. The values displayed are path coefficients. These beta weights can vary between –1.00 and + 1.00. (Error terms are omitted to improve readability.) The small underlined figures just outside the boxes represent proportions of variances accounted for by the dependent variables: the squared multiple correlations. Double arrows indicate covariances. Because the displayed model is standardized, these covariances are the bivariate correlations. The models from both Figure 2 and Figure 3 are compared in Table 3.

(Here Table 3)

In general, there are no, or at least very small, differences between the coefficients derived from both models. This result implicates that adding lecture quality does not lead to a change of the squared multiple correlations and the beta weights. Table 4 shows the comparison of the fit indices between the two models.

(Here Table 4)

As can be deduced from RMSEA and the corresponding p-value PCLOSE, both models yield a good fit with the data. Based on the fit indices, no model is to be preferred.

A third way to compare the two models is to investigate the differences of the chi-square statistic. The null-hypotheses is that both models fit he PBL-model equally well. A test of the stronger model (Model B) against the weaker one (Model A) can be obtained by subtracting the smaller chi-square statistic from the larger one. The new statistic is 0.225 (*i.e.* 22.865 – 22.640). If model B is correctly specified, this statistic will have an approximate chi-square distribution with degrees of freedom equal to the difference between the degrees of freedom on the competing models. The difference in degree of freedom is 1 (*i.e.* 11 – 10). That is, Model B imposes all of the parameter constraints of Model A, plus an additional 1.

With 1 degree of freedom, chi-square values greater than 3.841 are significant at the .05 level. Based on this test, the null-hypotheses is not rejected. Adding a new variable to the PBL model, lecture quality, does not lead to a better explanation of the PBL model.

DISCUSSION

The purpose of the study was to investigate the auxiliary role of lectures in PBL. We hypothesized the quality of lectures to be an independent input variable, which would entertain causal relationships with time spent on study, intrinsic interest in subject matter and achievement. This was based on the simple assumption that if the quality of lectures would play a role in a strongly student-centered instructional approach in which self-directed learning is valued, it had to be these elements of Schmidt and Gijselaers (1990) model of PBL. (The other elements are independent themselves.) The fits of two models were computed: one with lecture quality included as a determinant of learning, the other without lecture quality. If the hypothesis that lecture quality plays a positive role in problem-based learning was valid, the model, which included lecture quality, should account for more of the variance of the components and the general fit should be better. This hypothesis could not be confirmed. Lecture quality appears not to increase time spent on study, nor to increase the test score or intrinsic interest in subject matter.

This conclusion, based on our data, seems to be at odds with other observations made in problem-based programs. For instance, generally lectures are well attended by students. In addition, students find lectures moderately useful as demonstrated by data obtained from program evaluations. However, useful for what? The quality of lectures does not contribute to higher achievement nor does it increase interest in subject matter. There are however, some interesting correlations between lecture quality on one hand, and some model variables on the other (see Figure 3), which can, at least partly, explain the positive attitudes of students to lectures. There is a relatively high correlation between lecture quality and the quality of the problems in the unit guide (0.58): The higher the evaluations of the lectures, the higher

students perceive the quality of the problems (or visa versa). This result suggests that lectures clarify the problems, which is maybe why students actually attend the lectures. In addition, there is a high correlation (0.33) between the evaluation of the lectures and the perceptions of students of the quality of the organization of the educational block. This result is not studied in depth in this investigation, but it is possible that lectures help students to organize their study efforts. A third correlation is also of interest: The relatively high correlation (0.32) between lecture quality and the perceived relevance of the educational unit as a whole. The higher students evaluate the lectures, the more the educational unit is relevant for them. It seems that lectures function as a tool that put the content of the unit into a broader perspective. By attending the lectures, students get an overall view of the unit and of the place of the unit in the whole curriculum. Although this will not lead to a higher achievement score (see the low path coefficient, 0.09, in Figure 3), it certainly adds to the effectiveness of the unit as a means of preparing students for professional practice.

In conclusion, our study does not support the idea that the quality of lectures adds something to the problem-based learning model in terms of its outcomes. In fact, the model, as tested in previous studies (e.g., Schmidt, 1999; Van Berkel & Schmidt, accepted), was confirmed in the present study as well. However, this does not imply that we suggest that lectures could be deleted from these curricula. We believe that lectures may be an important means to help students putting the knowledge acquired into a broader, often professionally relevant, perspective. This is an important aspect of higher education that often can only be attained through the direct confrontation between students and these professionals, their teachers. However, if this is true, then it is important for teachers to be aware that lectures fulfill mainly this role, and that using lectures as a means of knowledge transmission is a waste of time. Students in PBL seem to have more efficient means to acquire knowledge, as demonstrated by the relations between achievement and other elements of PBL, unearthed in the present study and others.

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Table 1. Variables involved in the study, with their operational formulations

VARIABLES	ITEMS
Amount of Prior Knowledge	– This unit fitted well with my prior knowledge
Quality of the Problems	– The problems were clearly formulated
	– The problems were a good starting point for the group discussion
	– The problems were motivating to start the self-study
Tutor Performance	– The tutor functioned well
	– Rate the functioning of the tutor (1-5)
	– The tutor stimulated analysis of the problems
	– The tutor stimulated the group through her/his expertise
	– The tutor showed interest in my study activities
Lecture quality	– The lectures matched the subjects I was studying at that moment
	– The subject-matter was clearly presented in relation to the goals
Tutorial-Group Functioning	– The meetings were productive
	– The meetings were pleasant
Time Spent on Individual Study	– How many hours a week did you spend on self-study?(Indicate in whole hours)
Intrinsic Interest in Subject-Matter	– The subject-matter was interesting

Table 2: Intercorrelations, means and standard deviations of the aggregated scores on the variables (N=700)

	1	2	3	4	5	6	7	8
1. Amount of Prior Knowledge	-							
2. Intrinsic Interest in Subject Matter	0.48*	-						
3. Lecture quality	0.30*	0.35*	-					
4. Time spent on study	0.06	0.15*	-0.02	-				
5. Achievement	0.06	0.07	0.09*	0.02	-			
6. Quality of the Problems	0.42*	0.59*	0.58*	0.06	0.08*	-		
7. Tutor Performance	0.18*	0.17*	0.16*	-0.01	0.02	0.22*	-	
8. Small Group Functioning	0.27*	0.32*	0.24*	0.07	0.04	0.32*	0.58*	-
Means	3.5	3.8	7.2	16.5	3.1	10.9	19.3	7.6
Standard Deviations	0.58	0.71	0.95	4.90	0.34	1.13	2.64	1.13

* significant at the .05 level (2-tailed)

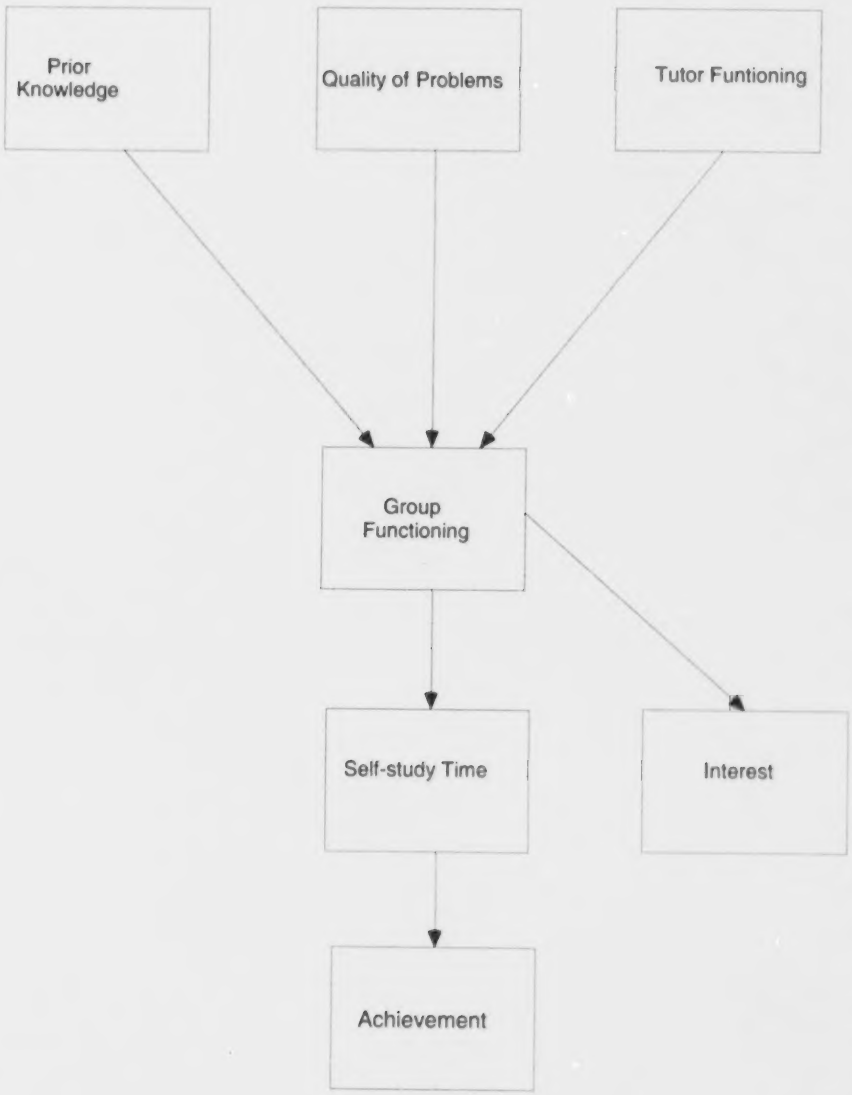
Table 3: Squared Multiple Correlations, and beta weights of two models

	Model A (excluding lecture quality)	Model B (including lecture quality)
Squared Multiple Correlations:		
Tutorial-Group Functioning:	0.39	0.39
Time Spent on Individual Study	0.00	0.01
Intrinsic Interest in Subject-Matter	0.43	0.43
Achievement	0.00	0.02
Beta Weights:		
Quality of Problems -> Tutorial-Group Functioning	0.16	0.16
Tutor Performance -> Tutorial-Group Functioning	0.52	0.52
Amount of Prior Knowledge -> Tutorial-Group Functioning	0.11	0.11
Tutorial-Group Functioning -> Time Spent on Study	0.07	0.08
Tutorial-Group Functioning -> Intrinsic Interest in Subject-Matter	0.10	0.10
Time Spent on Study -> Achievement	0.02	0.02
Quality of Problems -> Intrinsic Interest in Subject Matter	0.45	0.46
Amount of Prior Knowledge -> Intrinsic Interest in Subject Matter	0.26	0.27
Lecture quality -> Time Spent on Study		-0.04
Lecture quality -> Achievement		0.09
Lecture quality -> Intrinsic Interest in Subject-Matter		-0.02

Table 4: Fit indices of two models

	Model A (excluding lecture quality)	Model B (including lecture quality)
Chi-square	22.64	22.86
Degrees of freedom	10	11
P	0.01	0.02
CMIN/DF	2.26	2.08
RMSEA	0.04	0.04
PCLOSE	0.65	0.74
FMIN	0.03	0.03
FO	0.02	0.01
TLI	0.97	0.95
CFI	0.98	0.99

Figure 1: Theoretical Causal Model of Problem-Based Learning



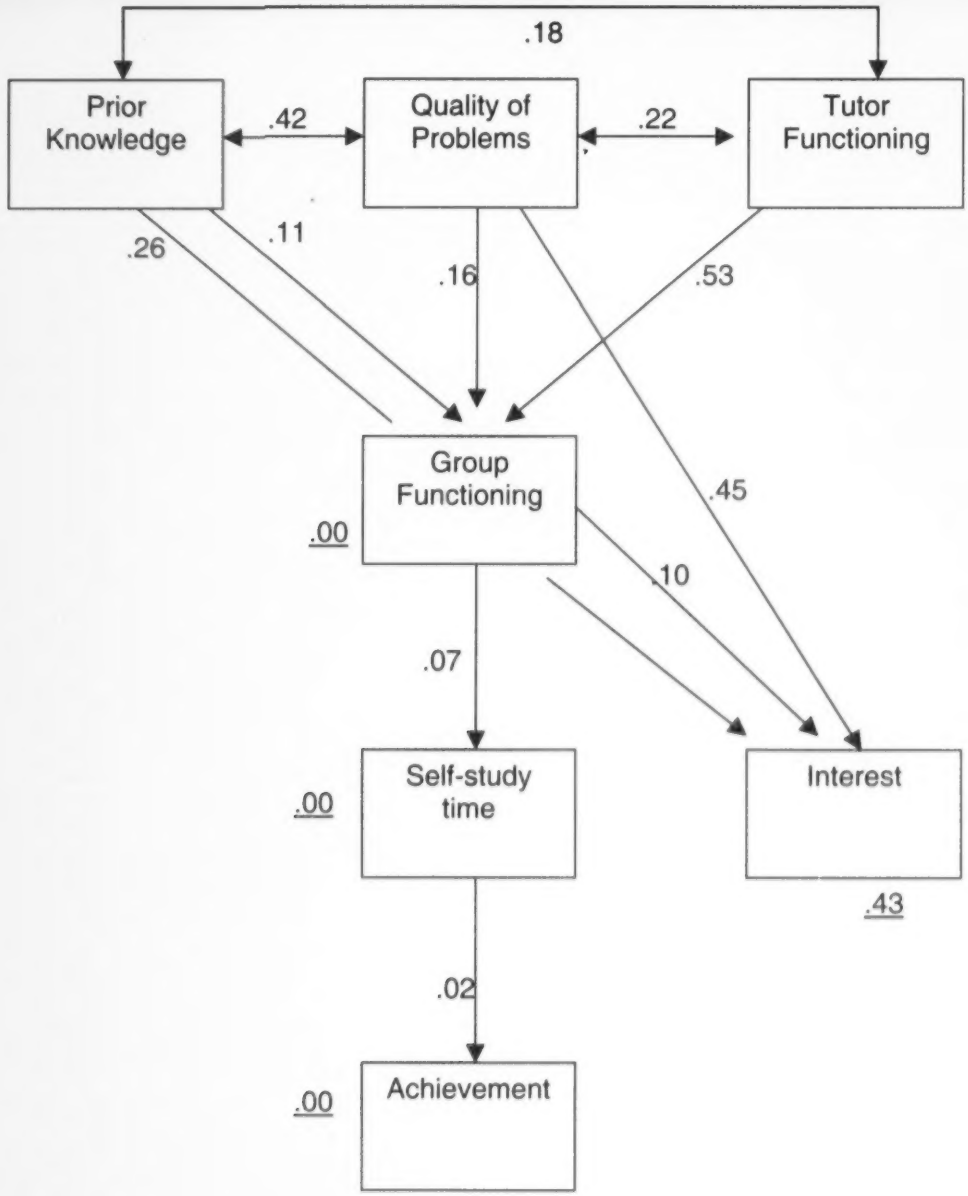


Figure 2: Alternative Causal Model of Problem-Based Learning

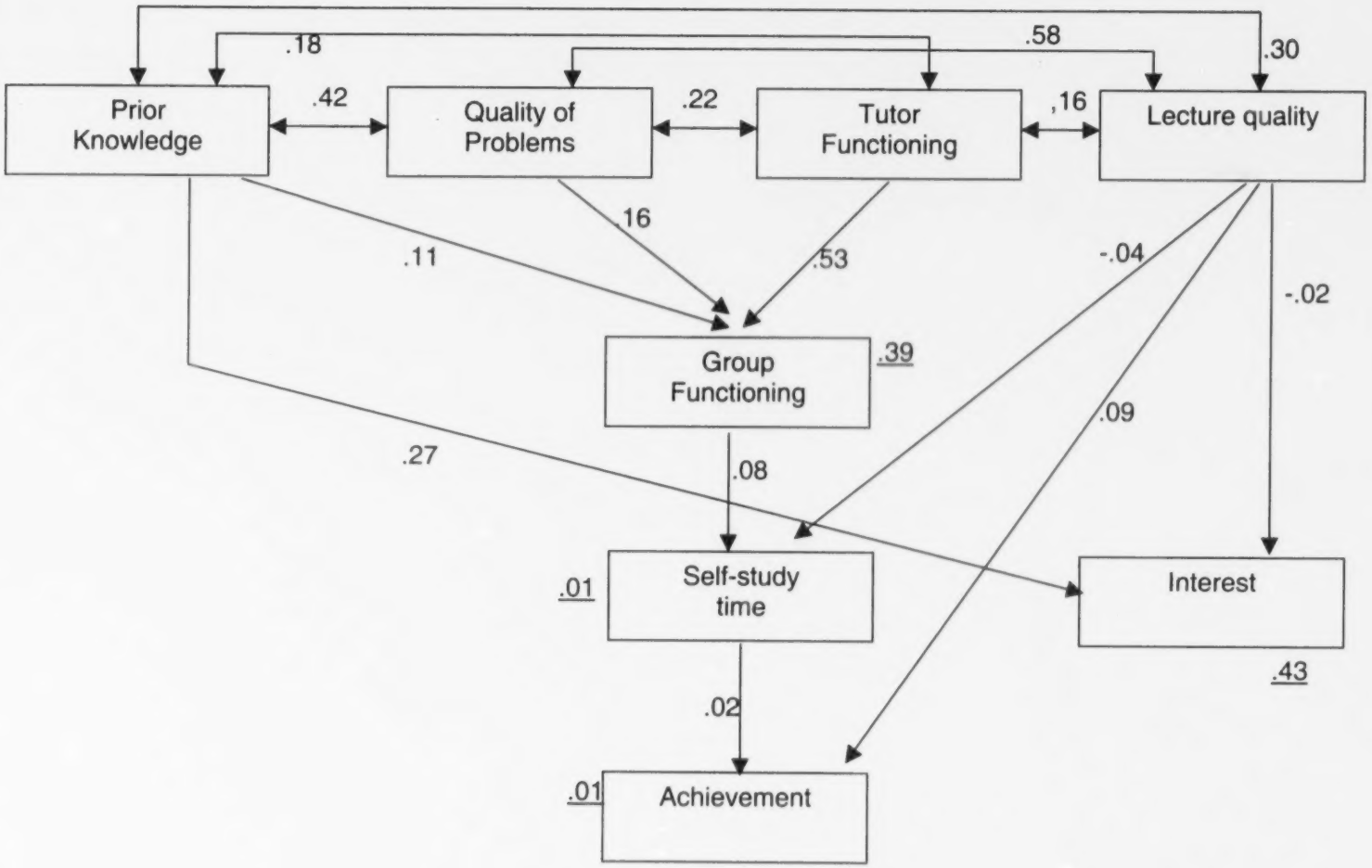


Figure 3: Alternative Causal Model of Problem-Based Learning including Lectures